

**STRUCTURAL TECHNOLOGY CHALLENGES FOR  
EVOLUTIONARY GROWTH OF SPACE STATION FREEDOM**

**HAROLD H. DOIRON  
MCDONNELL DOUGLAS SPACE SYSTEMS COMPANY  
SPACE STATION DIVISION  
HOUSTON, TEXAS**

52-13  
163653  
N93-27837  
p. 23

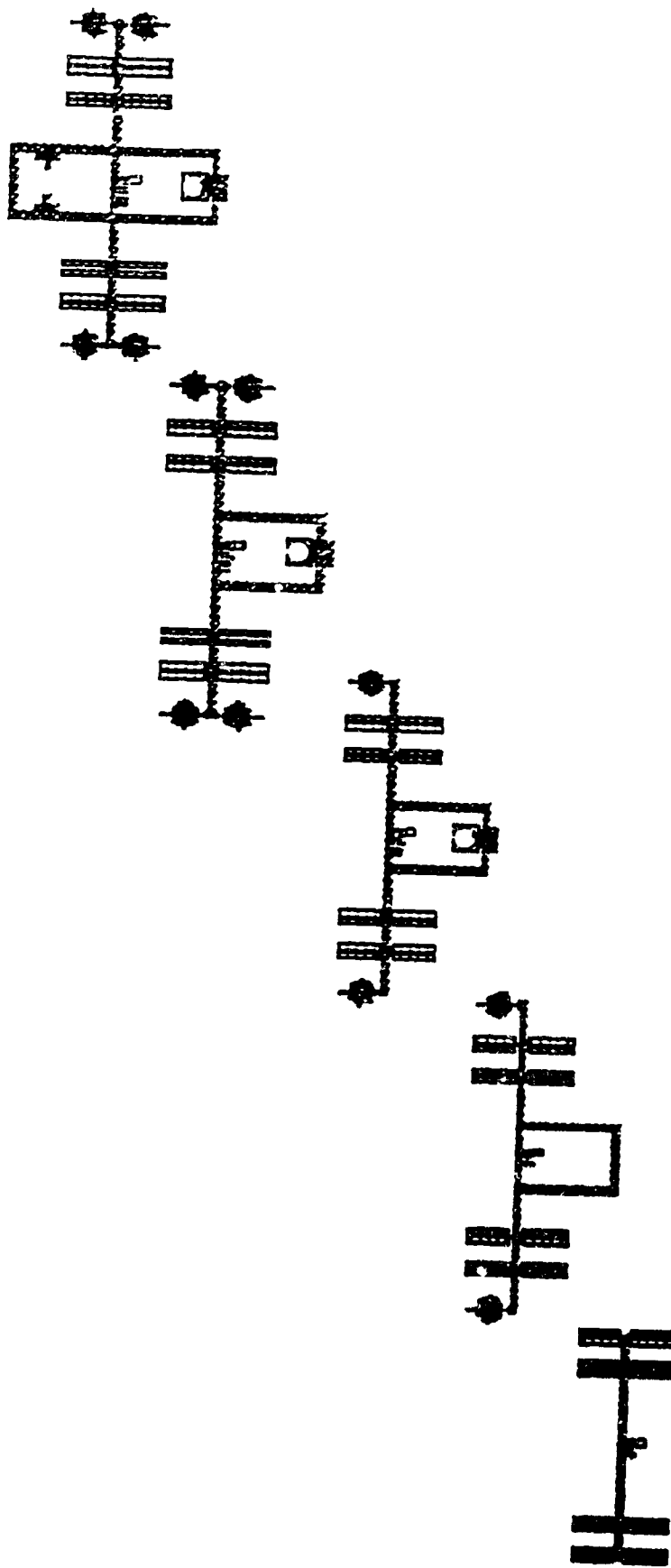
A proposed evolutionary growth scenario for Space Station Freedom was defined recently by a NASA task force created to study requirements for a Human Exploration Initiative. The study was an initial response to President Bush's July 20, 1989 proposal to begin a long range program of human exploration of space including a permanently manned lunar base and a manned mission to Mars. This growth scenario evolves Freedom into a critical transportation node to support lunar and Mars missions.

The growth scenario begins with the Assembly Complete configuration and adds structure, power and facilities to support a Lunar Transfer Vehicle (LTV) verification flight. Evolutionary growth continues to support expendable, then reusable LTV operations, and finally, LTV and Mars Transfer Vehicle (MTV) operations.

The significant structural growth and additional operations creating new loading conditions will present new technological and structural design challenges in addition to the considerable technology requirements of the baseline Space Station Freedom Program.

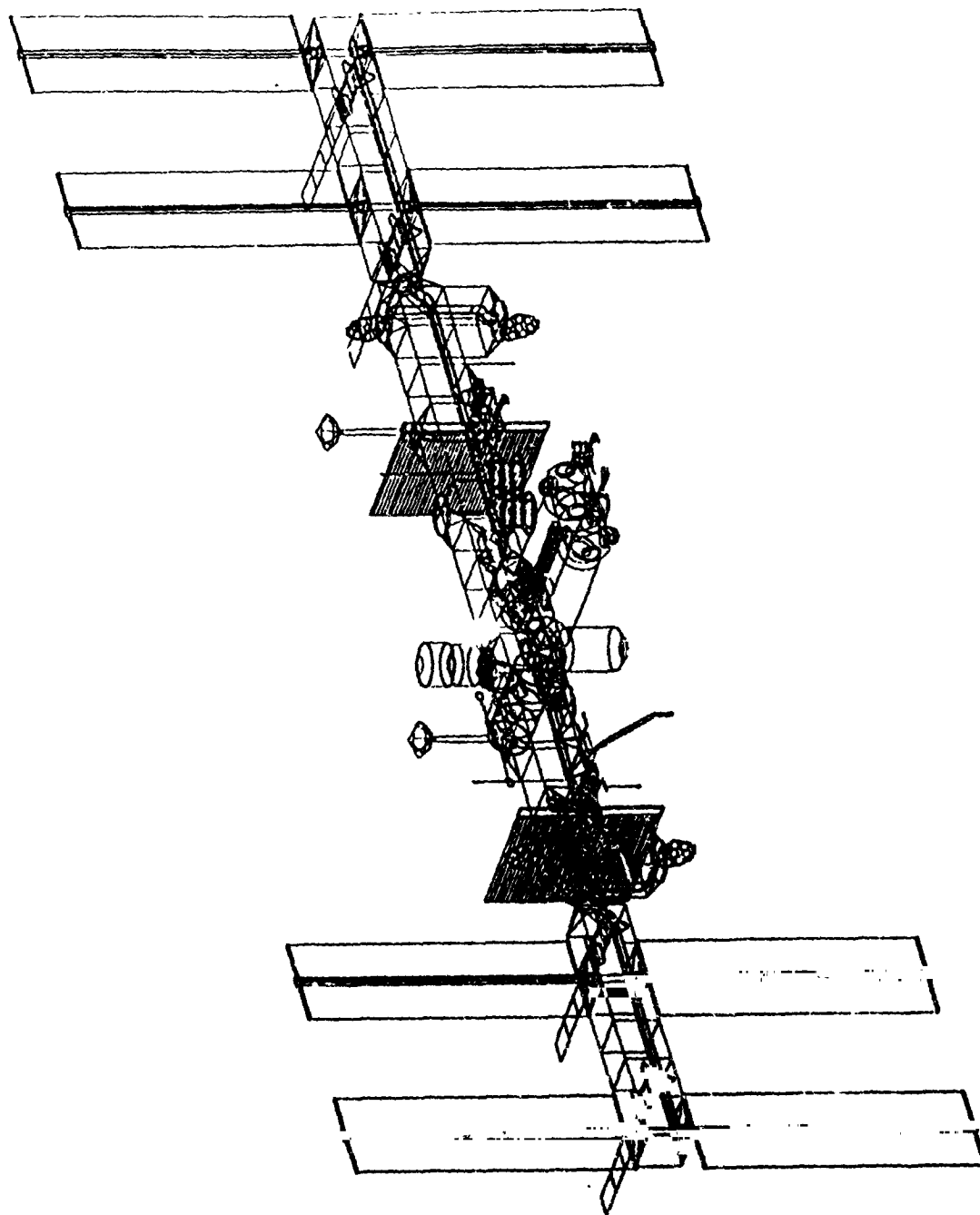
This briefing will review several structural design and technology issues of the baseline program and identify related technology development required by the growth scenario.

# TRANSPORTATION NODE EVOLUTIONARY GROWTH

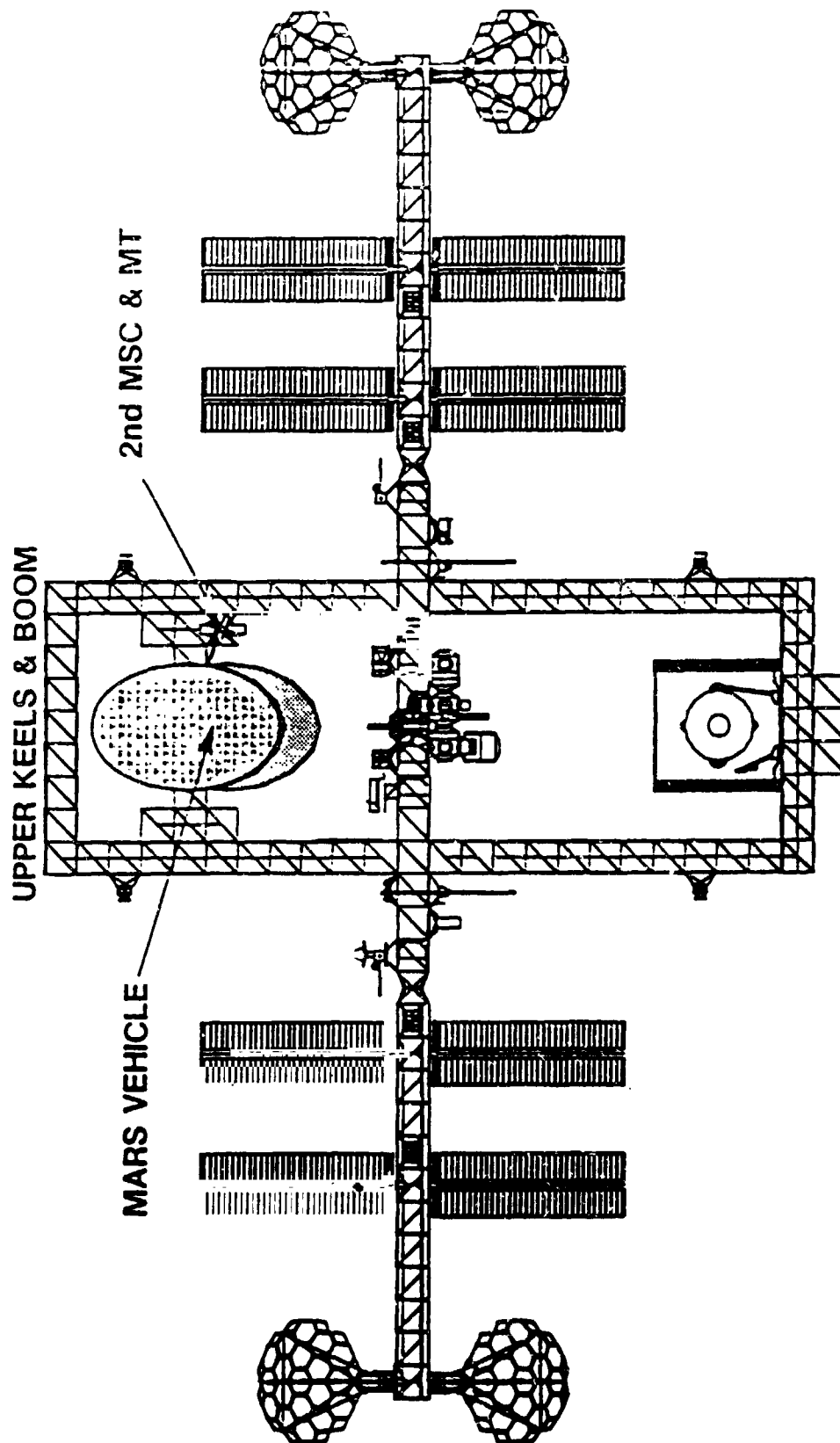


Baseline Assembly Complete	LTV Verification Flight	Expendable LTV Operations	Reusable LTV Operations	LTV and MTV Operations
----------------------------------	-------------------------------	---------------------------------	-------------------------------	---------------------------

ASSEMBLY COMPLETE CONFIGURATION



# LTV & MTV OPERATIONS CONFIGURATION



The Space Station Freedom and evolutionary growth configuration structures must be light weight with adequate strength to withstand imposed on-orbit loads, have adequate stiffness to preclude adverse structural/control interaction, allow for rapid and/or automated construction to minimize EVA time, be compatible with astronaut handling and translation requirements, and incorporate materials which will allow structural certification for a design life in excess of 30 years in the low earth orbit environment. In addition, the structure must be tolerant to damage from meteoroid and debris impacts or other accidental damage, allow for inspection and replacement of damaged structural members, and allow for growth to larger configurations.

These requirements present significant challenges for Space Station Freedom structural design. Growth requirements further drive the design to light-weight, stiff structures with dynamic characteristics which avoid adverse control systems interaction and which are capable of accommodating larger bending moments created by truss and keel extensions and new loading conditions.

## **SPACE STATION FREEDOM STRUCTURAL DESIGN DRIVERS**

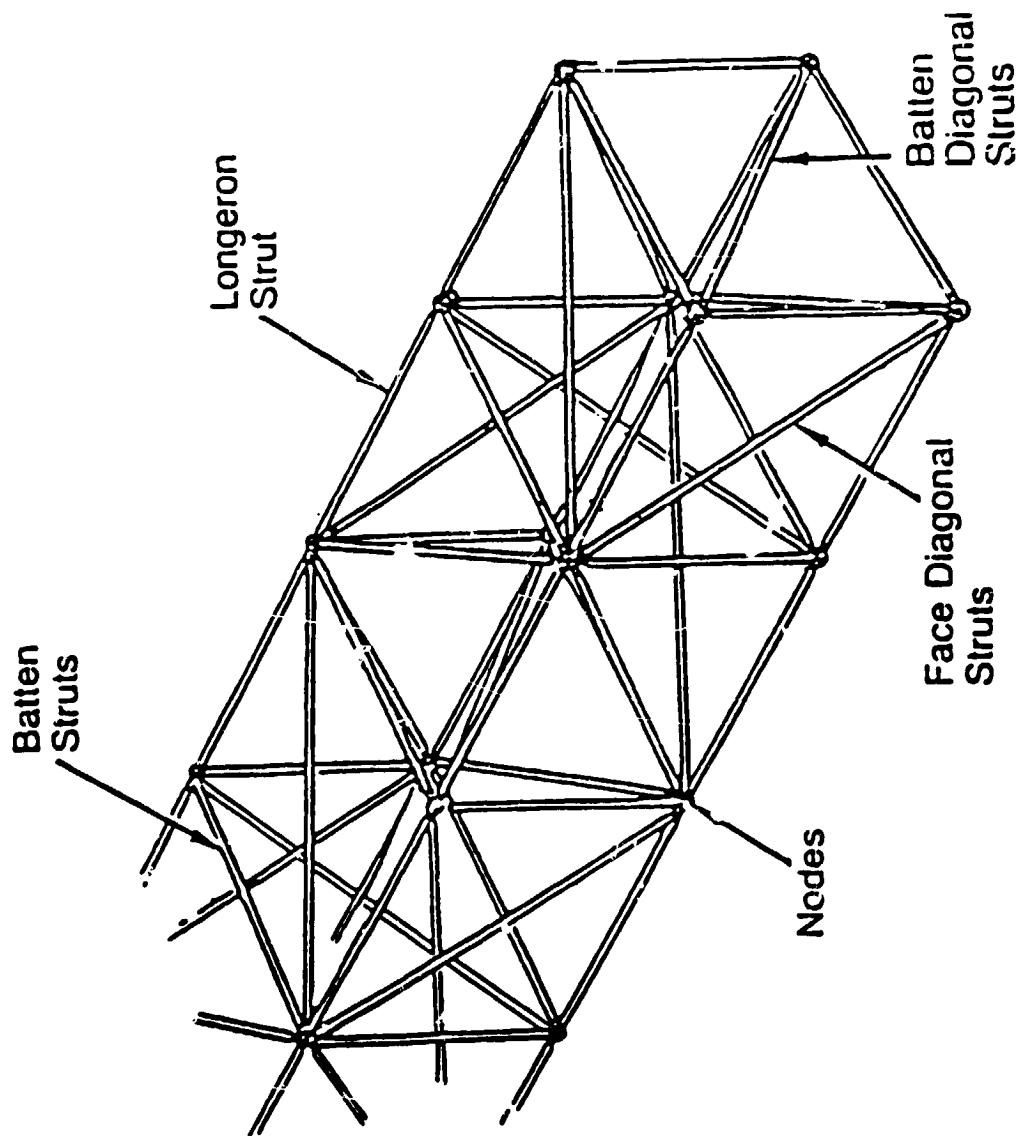
- **Light weight**
- **Adequate Strength**
- **Stiffness**
- **Rapid Construction**
- **Astronaut Handling/Translation**
- **30+ Year Design Life**
- **Damage Tolerance**
- **Damage Inspection and Repair**
- **Growth Capability**

The current five meter erectable truss design is a Warren truss utilizing alternating face diagonals and batten diagonals. Compared to an orthogonal tetrahedral truss, the alternating face diagonals offer 50 percent more torsional stiffness with one strut out (damage tolerant) and alternating batten diagonals provide greater lateral stability at the truss nodes with one strut out. Damage tolerance of the truss is achieved by requiring that the truss carry limit loads with a factor of safety of 1.0 with any one strut removed. The truss longeron and batten struts are 5.0 meters long (truss node center to truss node center) and the face and batten diagonals are 7.07 meters in length. Currently, the strut outer diameters are restricted to 2.0 inches to accommodate astronaut handling and hand-hold translation requirements.

The strut tubes are 30 msi modulus filament-wound graphite epoxy with wall thickness to be selected to accommodate design loads. A 0.005 inch thick aluminum foil is bonded to the outer surface of the graphite epoxy tubes for atomic oxygen and ultraviolet radiation protection. The graphite epoxy tubes are bonded and bolted to aluminum end fittings which contain the joint mechanism for attaching struts to truss nodes.



## FIVE METER ERECTABLE TRUSS

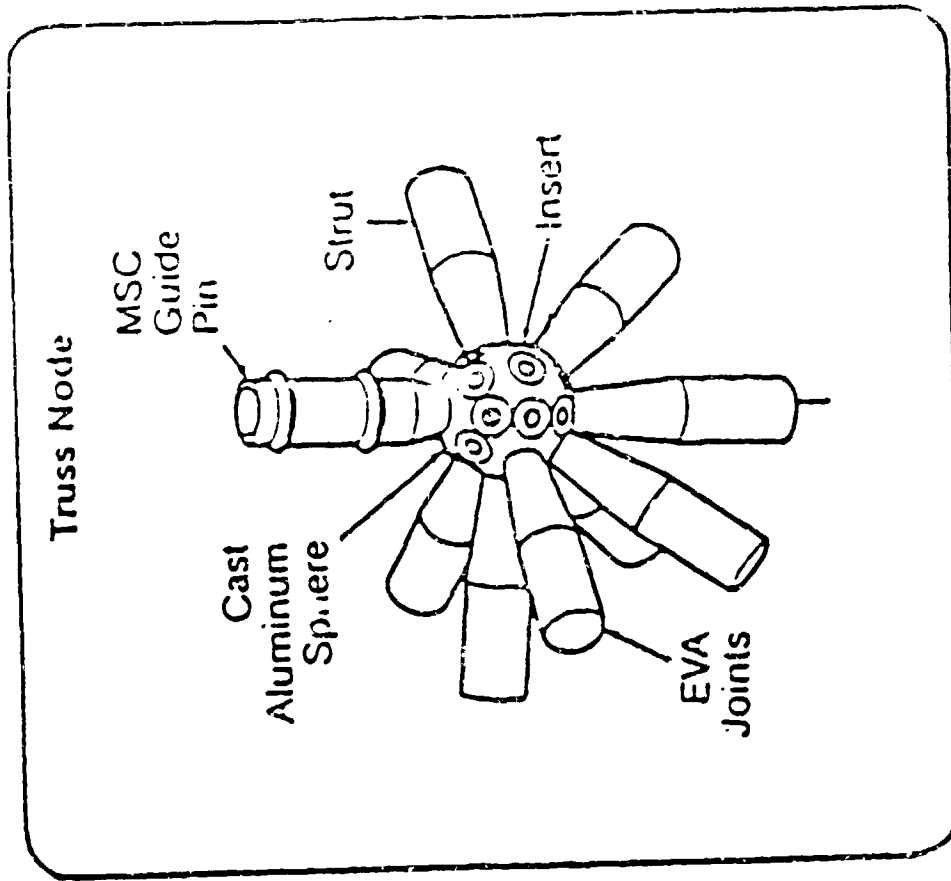


The truss nodes are 105 mm diameter hollow cast aluminum spheres with 26 machined flats containing inserts. The truss strut joint stubs and Mobile Transporter guide pins are bolted to the node at any of the 26 attach points. The attach points are designed to allow for unlimited orthogonal growth of the truss without interrupting the truss pattern. The joint stubs and MSC guide pins are bolted to the truss nodes prior to flight and pairs of truss nodes are pre-assembled to batten struts (in dumbbell fashion) to reduce EVA time on-orbit.

Joint mechanism selection has not been completed, but several mature designs have been tested and appear to be acceptable.

## TRUSS NODE

- Hollow cast aluminum sphere 105mm (4.13 in.) in diameter
- 26 machined flats with inserts
- Truss joint stubs and MSC guide pins are bolted to the node at any of the 26 attach points
- Attach points optimized to allow unlimited orthogonal growth without interrupting the truss pattern



Preliminary loads analyses have been conducted for the Permanently Manned Configuration and Assembly Complete configurations of Space Station Freedom. Loading events from Orbiter docking and plume impingement, module berthing, reboost and EVA and IVA crew activity and exercise were considered. The major structural loading events were found to be associated with Orbiter docking dynamics and RCS jet plume impingement on solar arrays, module berthing dynamics associated with abnormally high contact velocity resulting from a runaway manipulator arm and crew loads imposed during an inadvertent push-off from the 5 meter truss near the outboard ends of the truss.

These loading events created significant bending response of solar array masts and bending and torsional responses of the 5 meter truss. Orbiter RCS jet plume impingement on the large area solar arrays has been found to create particularly large loads on solar array masts and the 5 meter truss. These loads can be significantly affected by Space Station and Orbiter operational restrictions which are currently being studied. Buckling of individual members of the solar array mast and 5 meter truss is the critical concern. In the case of the 5 meter truss, the long strut member length combined with a desire to limit the strut diameter to 2 inches for astronaut handling and translation hand-hold capability result in some truss members being designed by buckling loads.

## DESIGN LOAD EVENTS

- Major Structural Loading Events
  - Orbiter Docking Dynamics
  - Orbiter RCS Jet Plume Impingement
  - Module Berthing
  - EVA Crew Loads
- Major Structural Load Concerns
  - Solar Array Masts Bending/Member Buckling
  - 5 Meter Truss Bending and Torsion Leading to Truss Member Buckling
    - 5 meter length longerons
    - 7.07 meter length diagonals
    - 2 inch OD struts for astronaut handling

Loads analyses should be conducted for various evolutionary growth configurations to identify loading events and characteristics and structural design sensitivity issues. New technology development requirements could also be identified such as automated docking systems designed to limit contact velocities and structural loads to allow for light weight structural design.

Extensions of the 5 meter truss in growth configurations create potential for larger bending moments on alpha gimbals and the central truss due to forces applied near truss tips such as RCS jet plume and crew EVA applied forces. Addition of keels creates highly loaded structure at the keel/transverse boom interfaces. Scarring the baseline structural design for growth requires more detailed knowledge of growth configurations and loading events from growth scenario operations.

Another structural design issue associated with evolutionary growth is that maximum loading conditions can occur during the construction operations before the final interim configuration is completed. Considerable effort on loads criteria development is needed for loading conditions which are associated with interim assembly configurations. Stochastic modeling of loading events may be required for efficient weight design. For example, if the critical load condition for an interim construction configuration results from docking dynamics, what degree of conservatism should be used for docking contact conditions for this one time event?

## **LOADS ISSUES FOR GROWTH CONFIGURATIONS**

- **Loads Analyses should be conducted to guide configuration selection and identify technology development requirements**
- **Extensions of the main 5 meter truss create potential for larger bending moments on alpha gimbals and central truss due to external forces applied near truss tips (plume, EVA)**
- **Addition of keels changes highly loaded areas of truss**
- **Spacecraft docking operations on upper and lower keels creates potential for large plume impingement and locking loads on transverse boom and keel structure**
- **Maximum loading events on individual truss members can occur during the construction process or for interim growth configurations. Loads criteria development including stochastic loads analyses required for weight efficient design.**

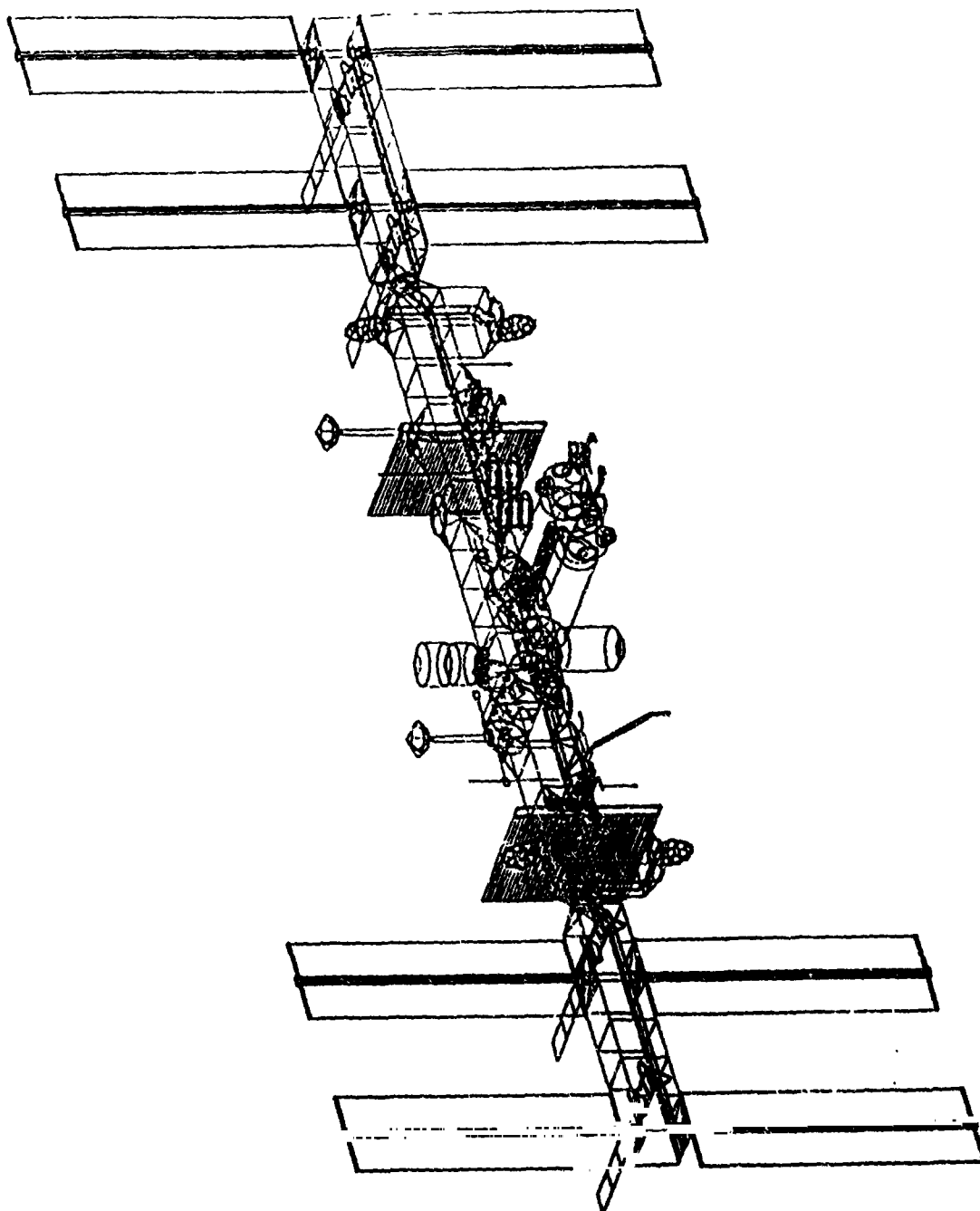
One aspect of large space structures such as Space Station Freedom is the inability to perform modal tests of full scale integrated configurations on Earth due to structural strength, suspension and facility size limitations. Dynamically scaled models and/or on-orbit modal testing may become requirements for structural dynamics verification. The arguments for scale model and on-orbit modal testing of Space Station Freedom are strengthened by the requirement that the structure must grow to a much larger size where structural/control interaction is a greater concern and modal frequencies are lower.

NASA LaRC is developing scale model testing technology through its Dynamic Scale Model Technology (DSMT) program.

NASA OAST has proposed a Space Station Structural Characterization Experiment (SSSCE) as an augmentation and enhancement of Freedom on-orbit structural dynamics verification. In addition to validating structural dynamics prediction technology for large space structures in general, this experiment would provide critical data to verify acceptable dynamic characteristics of growth configurations of Space Station Freedom. A Phase A feasibility study has been completed and Phase B concept definition and experiment simulation studies indicate important structural modes can be identified from free decay responses of the structure to reboost and/or intentional excitation from RCS thrusters. The experiment is being designed to have minimal impact on Freedom design and operations, and makes use of the existing Data Management System for data acquisition using accelerometers mounted to truss nodes and modules. Development of optical dynamic measurement technology has been identified as an attractive alternative to accelerometer measurements, especially for larger structures and long service life of the measurement system.

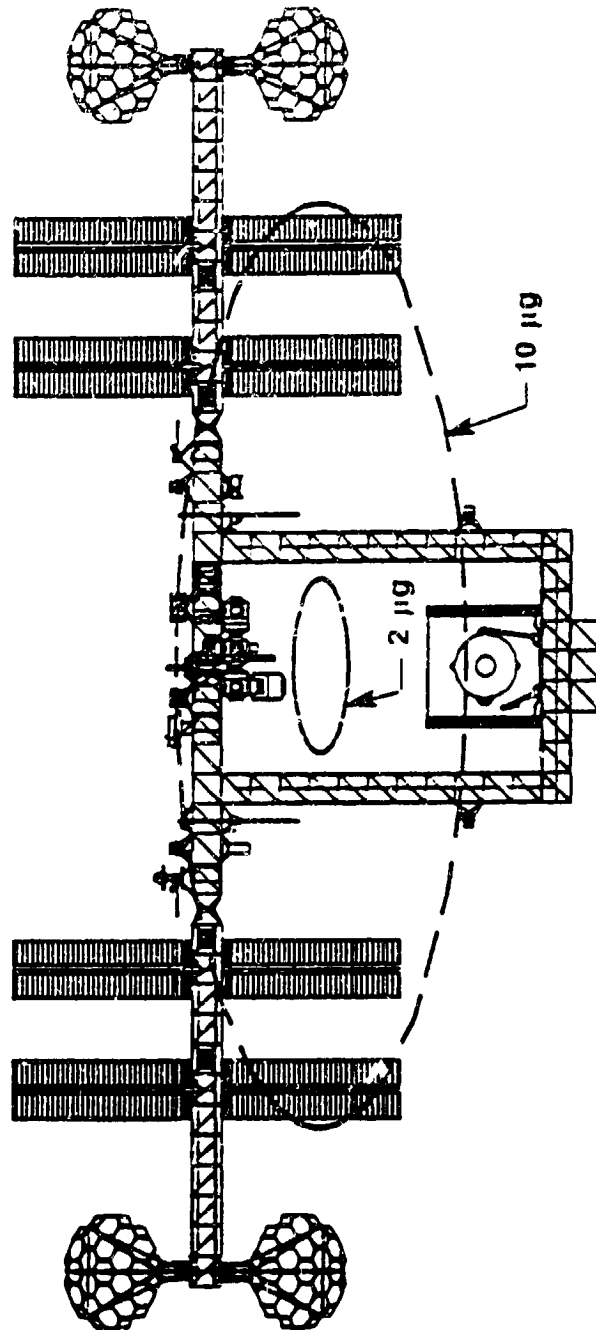


STRUCTURAL DYNAMICS VERIFICATION ISSUES



Some concern has been expressed that evolutionary growth of Freedom towards a primary role as a transportation node may compromise its role as a microgravity research laboratory due to degradation of quasi-static microgravity levels in laboratory modules caused by increased drag and center of mass movement away from laboratory modules. When dynamic aspects of the microgravity problem are considered, this concern may not be a major issue. Transient accelerations due to crew motions and exercise can be one to two orders of magnitude greater than drag or gravity gradient quasi-static G-levels due to rigid and flexible body responses of the structure. In previous studies of crew exercise and activity disturbances, as much as 2/3 of the transient acceleration was due to rigid body accelerations. As the Space Station grows more massive, the rigid body accelerations produced by crew motions will decrease linearly with mass increase. The relative importance of transient accelerations to quasi-steady acceleration for microgravity research is not well understood. A Microgravity Disturbance Experiment is planned for the STS-32 mission to further explore the effects of microgravity transient disturbances on crystal growth. Additional research and technical interchange between the structural dynamics and microgravity research communities are needed to further define microgravity requirements and disturbance and experiment isolation requirements.

# MICROGRAVITY ISSUES



Structural damage tolerance, detection, and repair of Freedom primary structure is required due to the long exposure to the meteoroid and debris environment and impracticality of shielding all structural members. Truss struts can be replaced by disconnecting the mechanical joint between truss struts and truss nodes and installing a new strut. More difficult, however, is the task of identifying struts which must be replaced. A visual inspection approach is currently proposed, but will be very expensive in terms of astronaut EVA time and of questionable accuracy due to possibility of internal non-visible damage to the composite truss tubes. Damage detection technology development is a key program need which is exacerbated by larger growth configurations.

One promising technology is damage detection and location through modal identification techniques. Implementation of this concept would require a long service life structural dynamics measurement system. Such a system could be shared by the SSCE and other users of structural dynamic data. Development of optical measurement systems for this purpose is a related technology need.

## **DAMAGE DETECTION AND REPAIR ISSUES**

- Damage tolerance, detection and repair required
  - Meteoroid and debris environment
  - Shielding all primary structures not practical
- Truss has damage tolerance through single strut out capability
  - Struts are replaceable
- Major concern is detecting damaged struts
  - Visual inspection baselined
    - EVA intensive
    - Accuracy?
  - Technology development desirable
- Modal damage detection and location
  - Modal ID detection technology development required
  - Long service life dynamic measurement system required
  - Optical measurement technology development desirable

Evolutionary growth requirements for Space Station Freedom present significant structural and related technology challenges. Loads analyses of growth configurations are required to identify structural design and related technology issues and specify the critical load requirements for the current Space Station Freedom Program. Technology development oriented to limiting imposed loadings from docking, berthing and proximity operations may be required to achieve weight efficient structural design. Criteria development for defining design load conditions for one time events during construction is needed. On-orbit modal identification methods development is needed to support damage detection and structural verification requirements. Long life certification of materials in the low Earth orbit environment is a concern and requires further technology development.

Finally, the technology issues associated with structures and evolutionary growth are not just structural issues. They are multidisciplinary in nature and will require considerable interaction between structural engineers and experts in other disciplines to achieve the best solutions to problems presented by evolutionary growth.

## CONCLUDING REMARKS

- Evolutionary growth capability presents significant structural and related technology challenges
- Loads analysis of growth configurations required to identify structural design and related technology development issues and specific scar requirements for Freedom
- Loads criteria development for construction phase required
- On-orbit modal identification methods development
  - Structural dynamics verification
  - Damage detection
- Long life certification of materials
- Technology issues are multidisciplinary, not just structural issues
  - Controls/structural interaction
  - Microgravity
  - Load limiting related technology (docking, berthing, prox ops, etc.)
  - Damage detection, inspection, repair
  - Meteoroid and debris protection
  - Astronaut compatibility